MODERN VIEWS OF THE ETHER.

Introduction.

In putting into print once more the book called "Modern Views of Electricity," my object is to recall attention to the ethereal aspect of affairs, and to assist in the combination of those ideas with the comparatively recent notion of electrons on the strength of which such great advances have been made. There are several additions to the book, and especially there is a concluding chapter which, since the other portions of the original book appeared in the columns of NATURE, may likewise be allowed so to appear. It will be observed that, on the basis of a consistent working hypothesis therein, an attempt is made to estimate the absolute value of the two ethereal constants—a thing which I have for many years sought to do. It will also be seen that, from the point of view adopted, the density of the ether comes out, not merely greater than platinum, as had several times been surmised, but very much greater: in fact, something comparable to a billion times the density of water, and its intrinsic constitutional energy is correspondingly enormous.

There is nothing paradoxical, nor, so far as I can see, improbable, about these figures. Matter is an excessively porous or gossamer-like structure, and the inertia of matter must be a mere residual fraction of the inertia of the continuous incompressible complex fluid, of which it is hypothetically composed, and in which it moves.

The following is the chapter referred to:—

CONCLUDING CHAPTER OR SUMMARY.

Structure of the Ether.

What, then, is the conclusion of the whole matter, so far as a conclusion is possible at present?

The material universe seems to consist of a perfectly continuous incompressible and inextensible medium, filling all space without interstices or breach of continuity;—not of a molecular or discrete structure, and as a whole completely at rest: as frictionless moreover, and unresisting to all ordinary motion of what we call matter through it, as is the mathematical conception—a perfect fluid. But in spite of immobility as a whole, it possesses that property of "rigidity," or elastic resilience to "shear," which is characteristic of what we ordinarily call a solid; wherefore it would appear that it must be, throughout, in such a state of excessively fine-grained turbulent motion as would confer this property upon it. And the resilience is so complete and instantaneous, without any delay or permanent set, that the elasticity must be described as "perfect." It is the gyrostatic kind of elasticity, discovered dynamically and applied ethereally by Lord Kelvin, whereby a perfect fluid can kinetically acquire some of the properties of a perfect solid.

It is well known that every solid possesses two kinds of elasticity—elasticity of bulk and elasticity of shape. The first or volume elasticity may also be called "the incompressibility," and is common to all forms of matter—fluid as well as solid. In the case of the ether, however, the value of this quantity appears to be infinite: it is, at any rate, greater than we have as yet been able to appreciate by specially directed experiments—meaning especially the Cavendish experiment referred to in §§ 4 and 14A. The elasticity of figure, or shape-elasticity, is only possessed by solids, and is technically called "rigidity"; it is small in the case of india-rubber, great in the case of steel or glass; it is the property on which spiral springs and torsion-balances depend. The two kinds of elasticity are quite independent of each other—quite independent also of anything akin to viscosity, which in the case of the ether appears to be zero.

Now something analogous to shape-elasticity the ether possesses. It does not possess ordinary mechanical rigidity, because that is an affair of molecules; but it possesses something which may be called an electric rigidity, or electromotive elasticity. It is identical with the electromotive elasticity of a dielectric,—it is the property which causes recoil after charge; and it has been denoted by $4\pi/\kappa$, where κ is the absolute Faraday's dielectric constant, or specific inductive capacity, for free space.

The property thus analogous to rigidity, or shape-elasticity, is accompanied by another property, akin to inertia. This is the property to which magnetism is due; it is a magnetic inertia, to pair with electric rigidity, and it has been denoted throughout by $4\pi\mu$, where μ is the absolute magnetic permeability of free space. The self-induction of quasi-inertia associated with every electric current, of which $4\pi\mu$ is the non-geometrical and essential factor, is explicable, up to a point, as due to the magnetic field excited by electric motion; but it would seem as if ultimately it must necessarily be dependent on an unexplained and fundamental kind of inertia possessed by the ether itself; so that the ether may be said to have a certain density, or mass per unit volume,—something at least so like ordinary material specific-gravity or density that we have to call it by the same name.

By reason of these two properties—electric elasticity and magnetic density—transverse electromagnetic waves are transmitted through and by the ether, at a perfectly definite and known speed. This speed of wave propagation is far greater than any we are accustomed to in connection with matter; and if ever the motion of matter can be made to approach this speed, it must encounter a reaction or impedance or opposition to further acceleration, which ultimately, in the limit, amounts to a practically infinite obstruction, at the actual critical speed.

This obstruction is not of the nature of friction,—it is not resistance proportional to the velocity, or in any way dependent on the velocity: it solely opposes acceleration, and is of the nature of impedance or inertia.

The fact of inertia enables an oscillatory wave-process to go on in the ether, and endows those oscillations with a particular kind of alternating kinetic, as well as with potential, energy.

The energy of strained or distorted ether is always potential energy, and is all the potential energy there is; but accessible or convertible kinetic energy is usually only possessed by those individualised and discriminated regions, or ethereal structures, which possess the power of locomotion, and which in their aggregate appeal to our senses as "matter."

During the passage of waves, the ethereal structure is sheared to and fro; not with any movement as a whole, but with equal opposite movement of two aspects, or elements, or conditions, of its structure: such shear being equivalent to what is called an electric displacement, and being subject to a restoring force accurately proportional to that displacement.

This elasticity is "perfect" in free space, apart from matter, until a critical shear, of unknown value, is reached. If strained beyond that, it may be supposed that a separation, or dislocation, or decomposition, of the ether into two components or constituents would occur;—constituents generated, as it were, by means of the shear, and probably not existing, as such, in the unperturbed ether. One of these components we call positive, and the other negative, electricity. Once formed they do not disappear again: they may combine—or approach each other so closely that they neutralise each other's effects at a distance; but they are still readily separable by electromotive force. They do not combine in the sense of destroying each other,—they do not re-form the original substance out of which they were produced.

The negative electricity, when separated, is freely mobile and easily isolated: it is what we experience as an electron. The positive constituent does not appear thus in an isolated manner, but is only known to exist in a mass, as if matted together and associated with an indistinguishable and inseparable aggregate of charges—opposite charges apparently in combination, going about as a whole. Some of these aggregates may unite into larger ones; others, when too large, may split up into smaller ones; and so finally a set of sub-permanent stable aggregates are formed, which we recognise as the atoms of the so-called "elements" of matter: each with its appropriate degree of stability.

These masses or aggregates may temporarily acquire, or may lose, one or more of the free electrons; and by thus becoming amenable to electrical or chemical attractions and repulsions, constitute what we call "ions," so long as the unbalanced or electrified condition lasts.

Massiveness of the Ether.

Each electron, moving like a sphere through a fluid, has a certain mass associated with it; dependent on its size, and, at very high speeds, on its velocity also.

Now how shall that mass be treated?

Shall we deal with it on the analogy of a sphere moving through a perfect irrotational liquid, without examining into details any further?

Or shall we consider it as generating circular lines of magnetic induction by its movement, by reason of the rotational properties of the ether, and attribute all its inertia to the magnetic whirl thus caused round its path: treating the whirl as an actual circulation of fluid excited by the locomotion?

Both methods may be adopted, to see whether they will agree.

Now treating it by the first method, and considering the electron merely as a sphere moving through a perfect liquid, its behaviour is exactly as if its mass were increased by half that of the fluid displaced and the surrounding fluid were annihilated. It has been argued in the book, from the result of the Cavendish surface-charge experiment, and from the phenomena of gravitation, that the ether is incompressible, to a high degree of exactness; and accordingly the density of fluid inside and outside an electron must be the same. So that, treating it in this simplest fashion, the resultant inertia is half as great again as that of the volume of fluid corresponding to the electron: that is to say, is $2\pi\rho a^3$, where ρ is the uniform density. If it is of some other shape than a sphere, then the numerical part is modified, but remains of the same order of magnitude.

Now treat it by the other, or magnetic whirl, method.

Let a spherical electron e of radius a be flying at speed u, so that the magnetic field at any point $r\theta$, outside, is

$$\mathrm{H}=\frac{eu\sin\theta}{r^2},$$

and the energy per unit volume everywhere is $\mu\mathrm{H}^2/8\pi$.

It has been shown by Lord Kelvin, Mr. Heaviside, G. F. FitzGerald, and Prof. Larmor, that a magnetic field may be thought of, hypothetically, as a circulation of fluid along the lines of magnetic induction—which are always closed curves—at some unknown velocity w.

Consider the energy per unit volume anywhere, it can be represented by the equivalent expressions

$$\tfrac{1}{2}\rho w^2=\frac{\mu\mathrm{H}^2}{8\pi}=\frac{\mu}{8\pi}\,\frac{e^2u^2\sin^2\theta}{r^4},$$

wherefore

$$\frac{w}{u}=\sqrt{\left(\frac{\mu}{4\pi\rho}\right)}\cdot\frac{e\sin\theta}{r^2};$$

On the cog-wheel analogy the highest velocity will be that in contact with the moving charge, and there is some reason to suppose that the maximum velocity w at the equator of the moving sphere may be equal to the speed u. Elsewhere it will decrease with the inverse square of the distance just as H decreases.

But without any hypothesis, if there be a circulation at all, its velocity must be a maximum at the equator of the sphere, where $r=a$ and $\theta=90$; so, calling this w_0,

$$\frac{w_0}{u}=\sqrt{\frac{\mu}{4\pi\rho}}\cdot\frac{e}{a^2},$$

and

$$\frac{w}{w_0}=\frac{a^2\sin\theta}{r^2},$$

and therefore the major part of the circulation is limited to a region not far removed from the surface of the electron.

The energy of this motion is

$$\tfrac{1}{2}\rho\int_0^\pi\int_a^\infty w^2\,.\,2\pi r\sin\theta\quad rd\theta\,.\,dr,$$

or substituting the above value of w the energy comes out equal to $\frac{4}{3}\pi\rho a^3\,{w_0}^2$.

Comparing this with a mass moving with speed u,

$$m=\frac{8}{3}\pi\rho a^3\left(\frac{w_0}{u}\right)^2.$$

This agrees with the simple hydrodynamic estimate of effective inertia, if $w_0=\frac{1}{2}\sqrt{3}u$; that is to say, if the whirl in contact with the equator of the sphere is of the same order of magnitude as the longitudinal rack-motion or cog-wheel spin at the same place.

Now for the real relation between w_0 and u we must make a hypothesis. If the two are considered equal, the effectively disturbed mass comes out as twice that of the bulk of the electron. If w_0 is much smaller than u, then the mass of the effectively disturbed fluid is much less even than the bulk of an electron; and in that case the estimate of the fluid-density ρ must be exaggerated enormously, in order to supply the required energy. It is difficult to suppose the equatorial circulation w_0 *greater* than u, since it is generated by it; and it is not unreasonable to treat them both as of the same order of magnitude. So, taking them as equal,

$$e=a^2\sqrt{\frac{4\pi\rho}{\mu}}$$

and $m=$ twice the spherical mass.

Hence all the estimates of the effective inertia of an electron are of the same order of magnitude, being all comparable with that of a mass of ether equal to the electron in bulk.

This would also be the conclusion drawn, if, instead of integrating the magnetic energy from a to infinity, we integrated from a to a larger radius b, or say na; the inertia would then come out

$$\tfrac{2}{3}\mu e^2\left(\frac{1}{b}-\frac{1}{a}\right)\quad\text{or}\quad\frac{2(n-1)}{3n}\,\frac{\mu e^2}{a},$$

and be still of the same order of magnitude for all reasonable values of n; the reason being that all the effective disturbance is concentrated in the neighbourhood of the charge.

Now the linear dimension of an electron is 10^{-13} centimetre diameter, and its mass is of the order 10^{-27} gram, being about the 1/700th part of the atom of hydrogen. Consequently, if its mass were due to its contents, the density of its material must be of the order

$$10^{-27}\div10^{-39}=10^{12}\text{ grams per cubic centimetre.}$$

This, truly, is enormous, but any reduction in the estimate of the circulation speed, below that of an electron, would only go to increase it; and since electrons move sometimes at a speed not far below that of light we cannot be accused of underestimating the probable velocity of magnetic spin by treating it as of the same order of magnitude, at the bounding surface of the electron: a relation suggested, though not enforced, by the cog-wheel and gyrostat analogy.

Incidentally, we may notice how enormous is the magnetic field surrounding the equator of an electron moving along an axis with, say, one-thirtieth the speed of light: it amounts to 10^{15} C.G.S. lines per sq. centimetre. And the magnetic energy there is correspondingly enormous, being 4×10^{28} ergs per c.c. At the velocity of light it would equal the constitutional energy of the ether itself.

Value of the Ethereal Constants.

It has been argued throughout the book that the ethereal density is what we know in magnetism as $4\pi\mu$; wherefore an approximate estimate of the absolute value of the magnetic constant μ for free space, on this view, is 10^{11} grams per c.c.

Using the value $4\pi\mu=\rho$, we get for the charge of an electron

$$e=4\pi a^2,$$

or comparable to its superficies.

The speed with which waves travel through the medium is the square root of 10^{21} C.G.S.; consequently the elasticity of the ether must be of the order 10^{33} dynes per square centimetre, which is what in static electricity we denote by $4\pi/\kappa$. Wherefore an approximate estimate of the absolute value of Faraday's dielectric constant κ, for free space, is 10^{-32} cubic centimetre per erg.

In other words, the intrinsic energy of constitutional motion of the ether, to which its rigidity is due, is of the order 10^{33} ergs or 10^{26} Joules per cubic centimetre—about a hundred foot lbs. per atomic volume; which is equivalent to the output of a million horse-power working for forty million years, in every cubic millimetre of space. It can otherwise be expressed as the energy of a thousand tons per cubic millimetre, moving with the velocity of light; but of course the motion really contemplated is all internal and circulatory.

Transmission of Waves.

Wherever electrons and atoms exist, they modify the ether in their immediate neighbourhood, so that waves passing through a portion of space containing them are affected by their presence, as if the ether were more or less loaded by them; because the electric displacements which go on in the unseparated and still perfectly united constituents of free ether are also shared to some extent by the separated peculiarities, especially by those of the electrons which are not too embedded in or surrounded by a positive charge—for instance, like a nucleus in a shell. These might be inert, and without influence on the light, except as small fixed mechanical obstructions; but all those charges which possess externally-reaching lines of force must share in the motion of the waves, without having the requisite amount of resilience to compensate for their inertia; consequently they, to that extent, constitute a retarding, and either an absorbing or a reflecting, agency.

Furthermore, their motions of vibration and rotation during the epochs of acceleration, however caused, encounter the inertia of the medium, and thereby excite waves in it—waves of oscillatory electric displacement with magnetic concomitant—and this electromagnetic radiation is transmitted out into space; but it is insignificant in amount unless the acceleration is violent. It is proportional to the square of the acceleration.

The positive and negative constituents, when they combine or cohere, do not destroy each other and revert into plain ether again; on the contrary, they retain their individuality and persist, in either a combined or separate state. We do not know how to produce or to destroy these peculiarities; and though atoms of matter are composed of them, and though all electrical phenomena and the excitation of radiation are due to their presence and behaviour, it is no more and perhaps not much less correct to say that the main bulk of the ether is composed of them than it is to say that actual sodium and chlorine exist in undissociated common salt. These elements only make their appearance when the original substance is decomposed. But certainly matter can be dissociated with extreme ease, whereas the dissociation of ether is unknown and hypothetical, save as represented by its apparent results.

Nevertheless, it must be the case that the slight, almost infinitesimal, shear, which goes on in a light wave, is of the nature of incipient and temporary electric separation; and all electromotive force *tends* to drive one constituent in one direction and the other in the other; thus beginning that individualisation or separate manifestation of the two ingredients, without a knowledge of which the original fluid would have appeared to be of a perfectly uniform and homogeneous character.

It is quite possible that the actually double aspect of ether is not only manifested, but really generated, by an electromotive force applied to it, just as the elastic recoil is so generated. It appears possible that a sufficiently violent E.M.F. applied to the ether, by some method unknown to us at present, must be the kind of influence necessary to shear it beyond the critical value and leave its components permanently distinct; such constituents being opposite electric charges, which, when once thoroughly separated, only combine to form matter, and do not recoil into ordinary ether again.

Hypothetical Longitudinal Stress.

Every attempt at separation of this kind, even if no stronger than exists in ordinary light, seems to be accompanied by a slight longitudinal force at right angles both to the displacement and to the orbital axis of the excursion—a force which is known as the normal pressure of light, or Maxwell's pressure, perpendicular to an advancing wave-front: the inertia of the constantly encroached upon region of free ether having the effect of momentum.

If the disturbance could be made so extreme as to result in permanent dislocation, this pressure might leave behind it, as permanent residue, a longitudinal pressure, extending throughout space inversely as the distance; whereby all the dislocated material would thereafter be urged together with a force which we know as gravitation, proportional in any piece of matter to the number of dislocated centres which go to compose it, and therefore proportional to its mass, irrespective of secondary accidents of a physical or chemical constitution.

Amplitude of Light Wave.

If a is the amplitude of shear during the passage of a wave of light, and if u is the maximum velocity of recovery, then

$$\frac{u}{v}=2\pi\frac{a}{\lambda},$$

where v is the velocity of light and λ the wave-length. The total energy per unit volume is $\frac{1}{2}\rho u^2$, where ρ is the density of the medium; for this represents twice the average kinetic energy, and of this quantity one-half is really kinetic, the other half potential.

Now direct thermal measurements, such as those conducted by Pouillet, give as the energy of sunlight near the earth 4×10^{-5} erg per c.c.; and consequently, in the region of intense light near the solar surface, the energy of radiation must be about 2 ergs per cubic centimetre. There may be more intense light than this, but this is the most intense we know of, so it is instructive to consider the amplitude of the shear corresponding to such violent illumination. Let us therefore put $\frac{1}{2}\rho u^2=2$, whence

$$u^2=4\times10^{-12}.$$

It follows, therefore, that

$$u/v=\tfrac{2}{3}\times10^{-16},$$

and accordingly the amplitude, of the most intense visible light we are acquainted with, is only 10^{-17} of a wave-length. The maximum strain is 2π times this fraction; and so the tangential stress thus called out in the medium, its rigidity being 10^{33}, may be estimated as comparable with 10^{17} dynes per square centimetre, or 10^{11} atmospheres.

The ordinary electrostatic unit of charge, on this estimate of ethereal elasticity, becomes 10^{-16} square centimetre, or the superficial dimension of an atom. This also corresponds with the estimate above, that the electronic charge is equal to the superficies of an electron; since one should be 10^{10} times the other.

The pressure of light has been represented by Prof. Poynting as a travelling momentum, like that of a jet of water, resulting in a pressure ρcv, where c is the velocity of longitudinal motion or circulation in the light beam, and v is the velocity of light. Taking the pressure of intensest light as 2 dynes per square centimetre, this gives $c=\frac{2}{3}10^{-22}$ centimetre per second: excessively small, therefore, even in that extreme case.

Hypothetical Flow along Lines of Magnetic Induction.

It has long been a working hypothesis with some mathematical physicists (see, for instance, the ensuing April number of the *Philosophical Magazine*) that there was probably something of the nature of a flow—an ethereal flow—along lines of magnetic induction; and the fact that these are always closed curves, in all known circumstances, is in favour of such an idea. The energy of the field would then be attributable to the energy of this flow; and though it is possible that the flow might be of the nature of components moving in opposite directions, the movement is hardly likely to be of this nature, since that would correspond with merely an electric current.

Fourteen years ago, in 1893, having rather perfect appliances for examining the effect of drift on the velocity of light, I carefully looked for some longitudinal flow along lines of magnetic force; repeating the experiments still more anxiously when I learnt that something of the kind was seriously suspected by Dr. Larmor.

Applying a field of 1400 C.G.S. units over a length of light path of about 14 metres in the aggregate, things were so arranged that a drift of 1 foot a second, or about 10^{-9}th of the velocity of light, would have been observed by a fractional shift of micrometrically viewed interference bands, if it had occurred. But no effect whatever on the interference bands could be detected, nor was anything observed when—with less perfect vision, in that case, owing to increased difficulties—the air along the field and path of light was replaced by bisulphide of carbon; except that, of course, if plane-polarised light was used, the plane was then rotated by a very large amount. Sufficient details of this series of negative experiments will be given in the forthcoming April issue of the *Philosophical Magazine.*

The result was to show that if the magnetic energy were to be accounted for in the assumed kinetic fashion, the density of the ether must be very considerable—in fact about 180 times that of water—in order to give the actual energy with a velocity below what could be observed in this way.

I have now, however, as described above, made a theoretical estimate of the density of the ether—arriving at the tentative conclusion that it is of the order 10^{12}—and we can therefore proceed to calculate what velocity of hypothetical ethereal drift is to be expected in any given magnetic field. It will come out, of course, exceedingly slow; for, on this view, the electromagnetic unit of field is $\mu^{-\frac{1}{2}}$, which equals 3×10^{-6} centimetre per second, and the velocity to be expected is the 2πth of that.

So, for instance, the field inside a solenoid, surrounded by a current of 100 amperes circulating 100 times round every centimetre of it, being $4\pi n_1 C$, will equal 12,000 C.G.S.; which corresponds with a velocity of 0·003 centimetre per second, or about 4 inches an hour. In fact, the ampere turns per inch, in any solenoid, measures the speed of magnetic circulation along its axis, no matter what the material of the core may be, in millimicrons per second.

When iron is substituted for air, the speed is the same; but the ethereal density is virtually increased, by the loading due to the molecular whirls in the iron.

It may seem difficult to reconcile this very slow velocity, in any ordinary field, with the great velocity, of the very same character, already postulated in the immediate neighbourhood of an electron; where it is supposed that the magnetic circulation is equal to, or at any rate of the same order of magnitude as, the locomotion speed—which it is well known may easily be 1/30th of the velocity of light, without departing appreciably from the simply calculated inertia. But that great speed, in the immediate neighbourhood of an electron, can be fully admitted; and there is nothing really inconsistent in that with the slow speed observed at any ordinary distance. For instance, if, close to the equator of a flying electron, the ethereal magnetic speed is 1/30th of the velocity of light, or 10^9 centimetres per second; then, at a distance of 1 millimetre away, the speed is reduced to 10^{-24}th of that value, and is, therefore, even at that small distance, only 10^{-15} centimetre per second, or 3 millimicrons per thousand years.

The speed at the axis of a solenoid is, of course, far greater than that, because of the immense number of electrons in any ordinary current surrounding it; but, in order to get up a drift-velocity of 1 centimetre per second in a solenoid, a thousand amperes would have to circulate three thousand times round every centimetre of it; which seems hardly practicable.

The optical arrangements, in my experiment above spoken of, could doubtless be improved sufficiently to show an ether drift of 1 centimetre per second; but I do not see how to produce a field of the required intensity to give even this leisurely flow. Such a field would have to be about four million C.G.S. units, and must exist throughout a great length of air.

The experimental verification of the above theoretical estimate of ethereal density seems therefore to be beyond the reach of this form of experiment. Nevertheless, I feel reasonably convinced that there is a justification for assuming the ether to have properties such as can only for the present be represented, in analogy with the properties of matter, by saying that its behaviour consistently indicates something typified by its possession of an immense elasticity or rigidity, 10^{33} dynes per square centimetre, caused by its intrinsic constitutional energy; combined with a property analogous to, and resulting in, material inertia, and typified by attributing to it a density of the order 10^{12} grams per cubic centimetre. The ethereal property, here called elasticity, is certainly the source and origin of every kind of material elasticity and potential energy; for the only real static effect producible in the particles of matter is a change in their arrangement or configuration. All stress must exist really in the ether.

Although the experimental methods so far suggested have proved themselves unable to test the magnitudes involved in these high values, some other method of inquiry may be suggested, and the theory may yet be brought to the test of experiment.

OLIVER LODGE.

THE INSTITUTION OF NAVAL ARCHITECTS.

THE annual spring meeting of the Institution of Naval Architects was held last week at the Society of Arts, commencing Wednesday, March 20, and being continued over the two following days. Fourteen papers were read and discussed, some of them at considerable length, while Lord Glasgow's presidential address, the report of the council, and other necessary business received due attention.

The first paper taken was a contribution by Mr. James McKechnie, of Barrow, the subject being the influence of machinery on the gun-power of the modern warship. This paper was full of information, but perhaps the most interesting part was that in which the author compared the elements of design of three imaginary battleships, propelled respectively by steam, gas, or oil engines. It is somewhat startling to find the chief engineer of one of our most powerful shipbuilding and engineering companies—and one, too, so largely engaged in the production of war material—should think gas or oil engines, as propulsive agents for the largest warships, sufficiently within the possibilities of the near future as to make it the subject of a paper before this important institution; it is prophetic of still vaster changes in store than even the transition from shell boilers to water-tube boilers, and from reciprocating engines to the steam turbine. Mr. McKechnie, however, intimated during the discussion on his paper that his company, Vickers, Sons and Maxim, was quite prepared to build a warship with gas-producers in place of boilers, and gas engines in place of steam engines, if any Government had the courage to give them an order. It would seem almost that steam's unconquerable arm is likely to have its supremacy challenged even in that field where we have hitherto held it to be most secure.

Mr. McKechnie takes for his comparison the designs of three battleships, each of 16,000 horse-power. The one propelled by steam would have machinery that would develop 10·1 horse-power per ton weight of machinery; the gas-driven machinery would give 14·48 horse-power per ton, whilst the oil engines and machinery would give off 21·33 horse-power per ton. Probably an oil-engined battleship may be considered outside the bounds of practical engineering application until oil fuel becomes far more plentiful than there appears to be any prospect of it being at present, waiting, of course, that gloomy but undefined era when the coal supplies of the world are exhausted. If, however, we confine ourselves to coal fuel, it is certainly a tempting offer which the engineer offers to the naval architect, this increase of nearly 50 per cent. in the power developed on a given weight. There are, however, other inducements. With the steam engine the area occupied by machinery per unit of power is 0·453 square foot, whilst of the gas engine but 0·336 square foot is needed for each horse-power developed. That also is a very substantial gain in a battleship, where every inch of space is so costly to produce and so urgently needed.

The third chief consideration Mr. McKechnie brings forward is fuel economy. Steaming at full power, the coal